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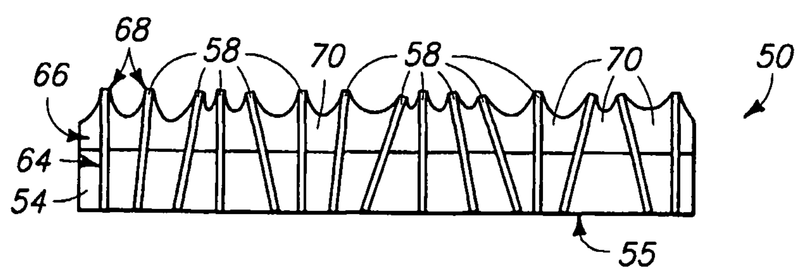
(54) Title: PROCESSES OF FORMING THERMAL TRANSFER MATERIALS, AND THERMAL TRANSFER MATERIALS



(57) Abstract: The invention encompasses a process of forming a thermal transfer material having low volatility. A substrate is provided, and a gelatinous mass is formed on a surface of the substrate. While the gelatinous mass is on the substrate, thermally conductive fibers are inserted into the mass. Subsequently, the gelatinous mass is removed from the substrate. The invention also encompasses a process of forming a thermal transfer material wherein a thermally conductive substrate is provided and a mass is adhered to a surface of the substrate. While the mass is on the substrate, thermally conductive fibers are inserted into the mass. The thermally conductive fibers extend to the surface of the substrate, but do not extend through the substrate. The substrate, mass and fibers together define at least a portion of a thermal transfer material. Additionally, the invention encompasses thermal transfer materials and methods of using thermal materials.

WO 02/067315 A2

Processes Of Forming Thermal Transfer Materials, And Thermal Transfer Materials

TECHNICAL FIELD

[0001] The invention encompasses processes of forming and using thermal transfer materials, and also encompasses various thermal transfer materials.

BACKGROUND OF THE INVENTION

[0002] Thermal transfer materials are desired in numerous modern applications for heat dissipation. Fig. 1 illustrates an exemplary environment in which thermal transfer materials can be utilized. Specifically, Fig. 1 illustrates a semiconductor device 10 comprising a circuit board 12 having a semiconductor die 14 bonded thereto. Circuit board 12 will typically have circuitry (not shown) extending therein. Die 14 has conductive interconnects 16 extending downwardly therefrom and connecting with the circuitry extending within circuit board 12. Die 14 can generate heat during operation, and accordingly is thermally connected to various thermal transfer devices. In the shown embodiment, die 14 is connected to a heat spreader 18 through a thermally conductive interface 20, and heat spreader 18 is further connected to a heat sink 22 through a second thermally conductive interface 24. Typically, heat spreader 18 will comprise a metallic plate, such as, for example, a copper or aluminum plate; and heat sink 22 will comprise a metallic structure fabricated to have a number of fins extending therefrom. Heat sink 22 can comprise, for example, a structure formed of aluminum or copper.

[0003] Thermally conductive material 20 comprises a material provided at the interface between semiconductor die 14 and heat spreader 18. Material 20 preferably has good thermal conductance along an axis from semiconductor die 14 to heat spreader 18; which can enable rapid and efficient transfer of heat from semiconductor die 14 to spreader 18. Similarly, thermal material 24 is provided at an interface between heat spreader 18 and heat sink 22 and preferably comprises good thermal conductive properties in a vertical direction between spreader 18 and sink 22 to allow rapid and efficient transfer of thermal energy from spreader 18 to sink 22. Thermal materials 20 and 24 can be in the form of, for example, sheets of thermally conductive material.

[0004] Fig. 2 illustrates another application for thermally conductive interface materials. Specifically, Fig. 2 illustrates an apparatus 30 comprising a housing 32 and a heat-generating device 34 retained within the housing. Device 34 can comprise, for example, an electrical device, and in one embodiment can comprise a plurality of the structures 10 of Fig. 1. Housing 32 comprises a thermally conductive material, and it is desired to transfer heat generated from device 34 to housing 32. Accordingly, a thermally conductive material 36 is provided at an interface between device 34 and housing 32. Material 36 can comprise materials similar to those described above with reference to materials 20 and 24, and accordingly can comprise a sheet of material provided within the interface between device 34 and housing 32.

[0005] The materials 20, 24 and 36 of Figs. 1 and 2 can be distinguished from one another based on their function in the various shown devices. Specifically, material 20 would typically be referred to as a Level I material in that the thermally conductive material 20 is utilized to transfer heat directly from a

semiconductor die to a heat dissipating device (shown as heat spreader 18). The material 24 would typically be referred to as a Level II device in that material 24 is formed as part of a chip package (shown as a package comprising circuit board 12, chip 14, heat spreader 18 and heat sink 22), but is not directly attached to a semiconductor die. Finally, material 36 would typically be referred to as a Level III material in that conductive material 36 is not directly associated with a semiconductor chip package, but rather is utilized for heat dissipation at a different scale than that associated with semiconductor chip packages.

[0006] Several materials have been developed for utilization as thermally conductive materials 20, 24 and 36, however improvement is desired amongst such materials. For instance, some applications for thermally conductive materials desire that the materials have very low volatility or outgassing. Such applications comprise, for example, space applications (such as, for example, satellite applications), and high vacuum applications (such as, for example, physical vapor deposition apparatus applications).

[0007] Volatilized components can be detrimental in space applications in that the volatilized components can redeposit on optics or other sensitive devices and cause costly problems. Further, volatilization of components from a thermally conductive mass can change an atmosphere proximate the mass and disrupt device performance of devices exposed to such atmosphere.

[0008] Volatilized components can also be disruptive in vacuum applications. For instance, in physical vapor deposition apparatuses it is generally desired to maintain a "clean" environment, meaning that an atmosphere within a vacuum chamber is carefully controlled within tight tolerances. Gases or particulates resulting from volatilization of a thermally conductive transfer material can disrupt

the internal environment of the vacuum apparatus and shift the environment outside of the pre-set tolerances, resulting in costly losses of process time.

[0009] Standard test method ASTM E 595-93 may be used to verify whether heat transfer materials meet outgassing criteria. ASTM E 595-93 suggests that suitable spacecraft materials (1) have a total mass loss of less than 1% in a day under conditions of 125°C and a pressure of 10^{-6} torr; and (2) have a volatile condensable mass loss of less than 0.1% in a day under the conditions of 125°C and a pressure of 10^{-6} torr. Volatile condensable mass is defined as mass which can be recondensed on a surface at a temperature of 25°C after the mass is lost from the thermal transfer material.

[0010] Space grade materials exist that can be used to produce thermally conductive interfaces. However, even when production methods use space grade raw materials, the resultant interfaces at times fail to meet the ASTM E 595-93 suggested critieria.

[0011] For the above-discussed reasons, it would be desirable to develop new thermal transfer materials, and in particular it would be desirable to develop thermal transfer materials having low volatility when exposed to vacuum environments.

SUMMARY OF THE INVENTION

[0012] In one aspect, the invention encompasses a process of forming a thermal transfer material having low volatility. A substrate is provided, and a gelatinous mass is formed on a surface of the substrate. While the gelatinous mass is on the substrate, thermally conductive fibers are inserted into the mass. Subsequently, the gelatinous mass is removed from the substrate.

[0013] In another aspect, the invention encompasses a process of forming a thermal transfer material wherein a thermally conductive substrate is provided and a mass is adhered to a surface of the substrate. While the mass is on the substrate, thermally conductive fibers are inserted into the mass. The thermally conductive fibers extend to the surface of the substrate, but do not extend through the substrate. The substrate, mass and fibers together define at least a portion of a thermal transfer material.

[0014] In other aspects, the invention encompasses thermal transfer materials and methods of using thermal transfer materials.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Preferred embodiments of the invention are described below with reference to the following accompanying drawings.

[0016] Fig. 1 is a diagrammatic, cross-sectional view of a prior art semiconductor chip package assembly.

[0017] Fig. 2 is a diagrammatic, cross-sectional view of a prior art thermal management assembly.

[0018] Fig. 3 is a diagrammatic, cross-sectional view of an initial portion of a thermal transfer material, shown at the preliminary step of a method of the present invention for forming a thermal transfer material.

[0019] Fig. 4 is a view of the material of Fig. 3 shown at a processing step subsequent to that of Fig. 3.

[0020] Fig. 5 is a view of the material of Fig. 3 shown at a processing step subsequent to that of Fig. 4.

[0021] Fig. 6 is a view of the material of Fig. 3, shown at a processing step subsequent to that of Fig. 5

[0022] Fig. 7 is a view of the Fig. 3 material shown at a processing step subsequent to that of Fig. 6.

[0023] Fig. 8 is a view of an assembly comprising the material of Fig. 7.

[0024] Fig. 9 is a diagrammatic, cross-sectional view of an initial portion of a thermal transfer material shown in accordance with a second embodiment method of the present invention for forming a thermal transfer material.

[0025] Fig. 10 is a view of the material of Fig. 9 shown at a processing step subsequent to that of Fig. 9.

[0026] Fig. 11 is a view of the material of Fig. 9 shown at a processing step subsequent to that of Fig. 10.

[0027] Fig. 12 is a view of an apparatus comprising the thermally conductive material of Fig. 11.

[0028] Fig. 13 is a view of a thermally conductive material formed in accordance with a third embodiment method of the present.

[0029] Fig. 14 is a view of a thermally conductive material formed in accordance with a fourth embodiment of the present invention.

[0030] Fig. 15 is a view of an apparatus comprising the thermally conductive material of Fig. 13.

[0031] Fig. 16 is a view of an apparatus comprising the thermally conductive material of Fig. 14.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0032] The invention encompasses new thermally conductive materials, and methods of forming thermally conductive materials. A first embodiment of the present invention is described with reference to Figs. 3-7. Referring initially to Fig. 3, a structure 50 is illustrated at a preliminary processing step of a method of the present invention. Structure 50 comprises a substrate 52 over which is formed a mass 54. More specifically, substrate 52 has an upper surface 56; and mass 54 is formed on such upper surface. Accordingly, mass 54 has a lower surface 55 against the upper surface 56 of substrate 52.

[0033] Upper surface 56 preferably comprises a material which is non-transferable relative to mass 54. Accordingly, substrate 52 can eventually be removed from beneath mass 54 without leaving remnants of substrate 52 on mass 54.

[0034] Mass 54 can be initially formed as a liquid on substrate 52 and then cured into a solid or semi-solid state. If mass 54 is cured into a semi-solid state, the cured mass can be referred to as a "gelatinous" mass.

[0035] Mass 54 preferably comprises a non-volatile composition, and in practice it is found that gel-type materials are often better suited for forming desired non-volatile compositions than are other materials. For purposes of interpreting this disclosure and the claims that follow, a non-volatile composition is defined as a composition having a total mass loss of less than 1% in 24 hours (i.e. 1 day) under conditions of 125°C and a pressure of 10^{-6} torr. Preferably, a non-volatile material will also have a total volatile condensable mass loss of less than 0.1% in a day under the conditions of 125°C and a pressure of 10^{-6} torr, with a "volatile condensable mass" being defined as a mass which can be

recondensed on a surface at a temperature of 25°C after the mass is lost from the thermal transfer material. A reason for keeping the volatile condensable mass loss particularly low is that volatile condensable masses can be particularly problematic. For instance, volatile condensable masses can cause severe problems in space applications if the masses are lost from a thermal transfer material and subsequently redeposited on optics or other sensitive devices.

[0036] Exemplary suitable materials for mass 54 are silicone-comprising materials, such as, for example, Nusil CV 8251™ and CV-2960™; and siloxane-comprising materials, such as, for example, Dow Corning 93-500™ and General Electric RTV 6166.

[0037] Referring next to Fig. 4, thermally conductive fibers 58 are inserted into mass 54. A method of inserting fibers 58 into mass 54 is electro-flocking, wherein mass 54 is provided with a first electrical charge, and fibers 58 are provided with a second and opposite electrical charge. Fibers 58 are thus attracted to mass 54, and typically will be partially embedded into mass 54 (as shown). Thermally conductive fibers 58 can comprise, for example, carbon fibers; with exemplary carbon fibers being obtained from AMOCO BP as THERMALGRAPH™ carbon fibers K-800X™ and K-1100™; and also being obtained from MITSUBISHI CHEMICAL as DIALEAD™ carbon fibers. Preferably, the fibers are desized prior to flocking the fibers into mass 54, with the term "desized" meaning that a sizing material is removed from the fibers. A suitable method for removing the sizing materials from carbon fibers is to bake the fibers at a temperature of about 500°C for about 1 hour at a pressure of about atmospheric, which typically is sufficient to ash the sizing materials. Conductive fibers 58 can be flocked into mass 54 to a density of greater than

about 5%, and preferably are flocked to a density in excess of 10% (with the density be expressed as a volume percent of the fibers relative to the volume of the mass).

[0038] Mass 54 can be provided in an uncured state prior to flocking of the fibers and subsequently cured. For instance, mass 54 can be in a primarily liquid state prior to the flocking of the fibers and subsequently cured into a semi-solid state.

[0039] Referring next to Fig. 5, structure 50 is provided between a pair of pressing structures 60 and 62. Structures 60 and 62 can comprise, for example, tool steel plates. Plates 60 and 62 are compressed relative to one another (with compressive forces being illustrated by arrows 64 and 66) to press fibers 58 into mass 54 and to accordingly seat the fibers against substrate 52. In the embodiment of Fig. 5, the compression of plates 60 and 62 against structure 50 is shown to bend (or bow) upper ends of fibers 58 as the fibers are pressed into mass 54.

[0040] In embodiments in which mass 54 is cured after flocking of the fibers, the pressing described with reference to Fig. 5 can occur before or after the curing of mass 54.

[0041] It is noted that even though both of structures 60 and 62 are illustrated to be compressed relative to one another, the invention encompasses other embodiments (not shown) wherein only one of the structures is displaced relative to the other. Also, it is to be understood that even though structures 60 and 62 are illustrated in the form of plates, the structures could comprise other shapes, and one of structures 60 and 62 can comprise, for example, a surface of a table or bench.

[0042] Referring next to Fig. 6, structure 50 is shown after removal from between plates 60 and 62. Fibers 58 have now returned to their original, substantially linear configuration (in other words, the bent tips of Fig. 5 have straightened). Also, fibers 58 are now seated against substrate 52, with each of the shown fibers 58 comprising a lower portion 64 retained within mass 54 and terminating in an end that is against substrate 52. Additionally, each of the shown fibers 58 comprises an upper portion 66 extending outwardly of mass 54 and terminating in a tip 68 (only some of the tips 68 are labeled).

[0043] A second mass 70 is formed over first mass 54, and between upper portions 66 of fibers 58. Mass 70 preferably comprises a low-volatility material, such as the siloxane or silicone materials described above. In particular embodiments, lower mass 54 can comprise a siloxane-containing material and upper mass 70 can comprise a silicone-containing material. Although upper mass 70 extends to about tips 68, tips 68 can remain relatively compliant compared to lower portions of fibers 58.

[0044] Referring to Fig. 7, substrate 52 (Fig. 6) is removed to leave a remaining structure 50 defined as a thermally conductive thermal transfer material comprising masses 54 and 70, and further comprising conductive fibers 58 extending through masses 54 and 70. It is noted that masses 54 and 70 would typically not be particularly thermally conductive, but instead the thermal conductance of material 50 is provided by the fibers 58 extending therethrough. Fibers 58 can thus be considered to define a path for thermal energy to be transferred through material 50. A preferred material 50 will have a thermal resistance of about 0.2 [°C in^2]/watt, or thermal conductance of about 5 watt/[in^2 °C].

[0045] As described previously, substrate 52 preferably has an upper surface 56 which can be removed from mass 54 without transferring any portion of substrate 52 to mass 54. A suitable material for upper surface 56 is TEFLON™ or some other flouroplastic exhibiting properties consistent with the aspects of the invention described herein. Upper surface 56 can consist essentially of, or consist of TEFLON™. Further, an entirety of substrate 52 can comprise, consist of, or consist essentially of TEFLON™ or another suitable fluoroplastic. Alternatively, substrate 52 can predominately comprise a material other than TEFLON™, with surface 56 being a TEFLON™ coating on such material. Regardless, substrate 52 preferably can be removed from mass 54 without leaving any of substrate 52 retained with mass 54. Accordingly, to the extent that substrate 52 may comprise volatile components, such volatile components are not transferred to or left adhered with mass 54.

[0046] It can be preferable that there be no material in an interface between substrate 52 and mass 54, and accordingly it can be preferred that mass 54 is on substrate 52 rather than separated from substrate 52 by an intervening material. In particular, it can be preferred that there be no adhesive or other material that would stick to mass 54 in an interface between substrate 52 and mass 54, as it can be preferred that no material remain associated with surface 55 of mass 54 once that mass 54 is separated from substrate 52. It is found that TEFLON™-comprising substrates 52 can typically be satisfactorily retained with mass 54 through electrostatic forces, rather than with intervening materials.

[0047] Referring to Fig. 8, a device 80 is illustrated showing material 50 in an application for thermally transferring heat from a first structure 82 to a second structure 84. Specifically, material 50 is provided between structures 82 and 84,

and is provided in an orientation such that fibers 58 extend from a surface of structure 82 to a surface of structure 84. In the shown embodiment, retaining bolts 86 and 88 are passed through structures 82 and 84, as well as through mass 50, to compress mass 50 between structures 82 and 84. Also, compliant tips 68 are shown pressed against mass 84.

[0048] It is noted that although the device 80 of Fig. 8 is shown with retaining bolts 86 passing through mass 50, it is to be understood that the invention encompasses other embodiments wherein a retaining structure is not passed through mass 50. For instance, the invention encompasses embodiments wherein retaining clips are utilized to hold structures 82 and 84 compressively with one another; and wherein such clips are provided at edges of structures 82 and 84, and accordingly do not pass through material 50.

[0049] In particular applications, material 50 can be compressed to pressures of 300 pounds per inch^2 (psi) or more. In such applications, it can be preferred to have high densities of fibers within material 50 so that material 50 is only modestly compressible, rather than being crushed by the high pressures. A suitable fiber density can be from about 10% to about 30% (with the fiber density expressed as a volume percent of the fibers relative to a remaining volume of material 50), with densities of greater than about 20% being preferred. Another advantage of high fiber density can be that higher fiber densities provide higher thermal conductance.

[0050] In a preferred embodiment, material 50 is retained between structures 82 and 84 only by the compressive forces generated by retaining members 86 and 88, and accordingly there is no adhesive or other binder provided between material 50 and either of the structures 82 and 84. The elimination of binder can

be preferred in that it can remove a possible source of volatile material from device 80. Also, the elimination of binder can enable "reworkable" interfaces between structures 82 and 84, and material 50. Specifically, if either of structures 82 or 84 is fragile, the structure could be destroyed in trying to remove a material retained on the structure with binder. In contrast, if material 50 is retained on the structure only through forces generated by retaining members 86 and 88, material 50 can be easily removed by simply releasing members 86 and 88. This can enable material 50 to be removed from a fragile structure, while leaving the structure in a condition to be reused (or "reworked") in a functioning device.

[0051] In alternative embodiments, a low volatility adhesive (not shown) can be utilized to bond material 50 to structure 82.

[0052] An advantage of utilizing the material 50 within the device 80, relative to prior art thermally conductive materials, is that material 50 preferably has low volatility associated therewith. Specifically, material 50 preferably has a total mass loss under a pressure of 10^{-6} torr and a temperature of 125°C of less than 1% in 24 hours. Further, material 50 preferably has a volatile condensable mass loss of less than 0.1% in one day.

[0053] A second embodiment of the present invention is described with reference to Figs. 9-12. Referring to Fig. 9, a partially-formed thermal transfer material 100 is illustrated at a preliminary processing step of a method of the present invention. Material 100 comprises a substrate 102 having a mass 104 formed thereover. Substrate 102 comprises a thermally conductive material, and can, for example, comprise a metal foil, such as copper foil or aluminum foil. Substrate 102 comprises an upper surface 106, and mass 104 formed over

upper surface 106. Mass 104 can comprise a gel and/or adhesive, and can, for example, comprise similar materials to those described above with reference to mass 54 of Fig. 3.

[0054] Preferably, mass 104 will be joined to upper surface 106 so that mass 104 is effectively non-removably coupled with material 102. In a particular embodiment, mass 104 can be adhered to substrate 102 utilizing a suitable adhesive (not shown), or alternatively mass 104 can be an adhesive material. Preferably, the adhesive will be substantially non-volatile in a final structure comprising mass 104 adhesively bound to substrate 102. Specifically, such final structure will preferably meet criteria wherein less than 1% of a mass of the final structure will volatilize within 24 hours at a temperature of 125°C under a pressure of 10^{-6} torr, and also wherein less than 0.1% of a mass of the final structure will volatilize as a volatile condensable mass within 24 hours.

[0055] Thermally conductive fibers 108 extend into mass 104. Fibers 108 can comprise, for example, carbon fibers identical to the fibers 58 described above with reference to Fig. 4, and can be flocked into mass 104 utilizing conditions similar to those described above with reference to Fig. 4 for flocking fibers 58 into mass 54.

[0056] Referring to Fig. 10, material 100 is placed between metal plates 60 and 62 and subjected to processing similar to that described above with reference to Fig. 5. Such processing seats fibers 108 against substrate 102. It is noted that fibers 108 are pushed against lower substrate 102, but preferably do not penetrate into or through the material of lower substrate 102.

[0057] Referring to Fig. 11, material 100 is shown after removal from between plates 60 and 62, and after formation of a second mass 110 over first mass 104.

Second mass 110 can comprise materials identical to those discussed previously with reference to mass 70 of Fig. 6, and can be formed by methodology identical to that described with reference to Fig. 6 for forming mass 70.

[0058] The material 100 of Fig. 11 is in the form of a sheet, and accordingly is a discrete thermally conductive material that can be placed between a pair of structures to conduct heat from one of the structures to the other. The sheet can be either pliable, or substantially rigid, depend on the thickness and physical characteristics of substrate 102 and masses 100 and 110. For instance, if substrate 102 is a thin metallic foil and the masses are gelatinous, the sheet can be a pliable structure.

[0059] Referring to Fig. 12, thermal transfer material 100 is shown incorporated into an apparatus 120. Specifically, apparatus 120 comprises a first structure 122 and a second structure 124, with thermal transfer material 100 being provided between structures 122 and 124. Further, apparatus 120 comprises retaining members 126 and 128 which compress thermal transfer material 100 between structures 122 and 124. Retaining members 126 and 128 are shown in the form of bolts, but it is to be understood that members 126 and 128 can comprise other forms, such as, for example, clips. Material 100 conducts heat between structures 122 and 124. Specifically, thermally conductive substrate 102 of material 100 is against structure 124, and fibers 108 extend from substrate 102 to contact a lower portion of structure 122. Accordingly, thermal energy can be conducted between structures 124 and 122. For instance, if structure 124 is hotter than structure 122, heat can transfer from structure 124 to thermally conductive substrate 102; and then from substrate

102, through thermally conductive fibers 108, and to structure 122. The heat is thus passed from structure 124 to structure 122 which can enable efficient cooling of structure 124. It is to be understood that material 100 enables heat to be transferred between structures 122 and 124, and accordingly, heat can be transferred from structure 122 to structure 124, as well as to be transferred from structure 124 to structure 122.

[0060] In a preferred embodiment, material 100 is retained between structures 122 and 124 only by the compressive forces generated by retaining members 126 and 128, and accordingly there is no adhesive or other binder provided between material 100 and either of the structures 122 and 124.

[0061] Another embodiment of the present invention is described with reference to Fig. 13. Specifically, a thermally conductive material 50a is shown at a processing step similar to that at which material 50 is shown in Fig. 6, and accordingly is shown at a processing step subsequent to that of Fig. 5. Material 50a differs from the material 50 of Fig. 6 in that material 50a lacks the second gel 70 shown associated with material 50. Accordingly, material 50a has fibers 58 extending upwardly above mass 54, and the tips 68 of fibers 58 are entirely free of encapsulating material.

[0062] Fig. 14 illustrates yet another embodiment of the present invention. Specifically, Fig. 14 shows a thermally conductive material 100a analogous to the material 100 of Fig. 11, but without the upper encapsulant 110. Accordingly, fibers 108 of material 100a have tips extending above gel 104, with such tips being substantially free of encapsulant.

[0063] Fig. 15 illustrates material 50a (from Fig. 13) incorporated into a device 80a analogous to the device 80 of Fig. 8. Substrate 52 (Fig. 13) is

removed prior to incorporation of material 50a into device 80a. It is noted that although the thermally conductive material 50a of Fig. 15 is shown only loosely compressed between structures 82 and 84, the conductive fibers of material 50a still reach from substrate 82 to substrate 84 to thermally connect the structures.

[0064] Fig. 16 illustrates material 100a (from Fig. 14) incorporated into a device 120a analogous to the device 120 of Fig. 12. Although the thermally conductive material 100a of Fig. 16 is shown only loosely compressed between structures 122 and 124, the conductive substrate 102 of material 100a rests against structure 124 while the fibers reach to the other structure 122 so that material 100a thermally connects structures 122 and 124 with one another.

[0065] The invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or modifications within the proper scope of the appended claims appropriately interpreted.

CLAIMS

We claim:

1. A method of forming a thermal transfer material, comprising:

providing a substrate;

forming a first gelatinous mass on a surface of the substrate, at least the surface of the substrate having a composition preventing transfer of volatile components from the substrate to the first gelatinous mass;

while the first gelatinous mass is on the substrate, inserting thermally conductive fibers into the mass; and

after the inserting, removing the first gelatinous mass from the substrate; the gelatinous mass having the inserted fibers therein defining the thermal transfer material.

2. The method of claim 1 wherein the inserting comprises flocking the fibers into the first gelatinous mass.

3. The method of claim 1 wherein the inserting comprises:

flocking the fibers into the first gelatinous mass; and

pressing the flocked fibers relative to the first gelatinous mass.

4. The method of claim 1 wherein the thermally conductive fibers are carbon fibers.

5. The method of claim 1 further comprising forming a second gelatinous mass over the first gelatinous mass after inserting the fibers into the first gelatinous mass.

6. The method of claim 1 further comprising forming a second gelatinous mass over the first gelatinous mass after inserting the fibers into the first gelatinous mass; and wherein the inserting comprises:

flocking the fibers into the first gelatinous mass; and

pressing the flocked fibers relative to the first gelatinous mass.

7. The method of claim 6 wherein one of the first and second gelatinous masses comprises silicone and the other of the first and second gelatinous masses comprises siloxane.

8. The method of claim 1 wherein the first gelatinous mass comprises silicone.

9. The method of claim 1 wherein the first gelatinous mass comprises siloxane.

10. The method of claim 1 wherein the surface of the substrate consists essentially of TEFLON™.

11. The method of claim 1 wherein an entirety of the substrate consists essentially of TEFLON™.

12. The method of claim 1 wherein the surface of the substrate comprises TEFLON™.

13. The method of claim 1 wherein the thermal transfer material meets the parameters of (1) having a total mass loss of less than 1% in a day under conditions of 125°C and a pressure of 10^{-6} torr; and (2) having a volatile condensable mass loss of less than 0.1% in a day under the conditions of 125°C and a pressure of 10^{-6} torr; wherein the volatile condensable mass is defined as mass which can be recondensed on a surface at a temperature of 25°C after the mass is lost from the thermal transfer material.

14. A method of forming a sheet of thermal transfer material, comprising:

providing a thermally-conductive substrate;

forming a mass attached to a surface of the substrate;

while the mass is on the substrate, inserting thermally conductive fibers into the mass, the thermally conductive fibers extending to the surface of the substrate, but not extending through the substrate; and

wherein the substrate, mass and fibers together define at least a portion of the sheet of thermal transfer material; the thermal transfer material meeting the parameters of (1) having a total mass loss of less than 1% in a day under conditions of 125°C and a pressure of 10^{-6} torr; and (2) having a volatile condensable mass loss of less than 0.1% in a day under the conditions of 125°C and a pressure of 10^{-6} torr; wherein the volatile condensable mass is defined as mass which can be recondensed on a surface at a temperature of 25°C after the mass is lost from the thermal transfer material.

15. The method of claim 14 wherein the forming a mass attached to the surface comprises applying an adhesive between the surface and the mass.

16. The method of claim 14 wherein the inserting comprises flocking the fibers into the mass.

17. The method of claim 14 wherein the inserting comprises:

flocking the fibers into the mass; and

pressing the flocked fibers relative to the mass.

18. The method of claim 14 wherein the thermally conductive fibers are carbon fibers.

19. The method of claim 14 wherein the mass comprises silicone.

20. The method of claim 14 wherein the mass comprises siloxane.

21. The method of claim 14 wherein said mass is a first mass, and further comprising forming a second mass over the first mass after the inserting.

22. The method of claim 14 wherein the thermal transfer material sheet is pliable.

23. The method of claim 14 wherein the substrate comprises a metal foil.

24. A sheet of thermal transfer material, comprising:

a thermally conductive substrate;

a mass attached to a surface of the thermally conductive substrate;

thermally conductive fibers extending into the mass, the thermally conductive fibers extending to the surface of the substrate, but not extending through the substrate; and

wherein the thermal transfer material meets the parameters of (1) having a total mass loss of less than 1% in a day under conditions of 125°C and a pressure of 10^{-6} torr; and (2) having a volatile condensable mass loss of less than 0.1% in a day under the conditions of 125°C and a pressure of 10^{-6} torr; wherein the volatile condensable mass is defined as mass which can be recondensed on a surface at a temperature of 25°C after the mass is lost from the thermal transfer material.

25. The sheet of claim 24 further comprising an adhesive between the surface and the mass.

26. The sheet of claim 24 wherein the mass defines a gelatinous material.

27. The sheet of claim 24 wherein the thermally conductive fibers comprise carbon fibers.

28. The sheet of claim 24 wherein the thermally conductive substrate is a metal foil.

29. The sheet of claim 24 wherein the mass comprises at least one of silicone and siloxane.

30. A thermal transfer material produced by the method of claim 13.

31. The material of claim 30 wherein the thermally conductive fibers comprise carbon fibers.

32. The material of claim 30 wherein the first gelatinous mass comprises at least one of silicone and siloxane.

33. A thermal transfer material, comprising:

a substrate;

a gelatinous mass on a surface of the substrate, at least the surface of the substrate having a composition preventing transfer of volatile components from the substrate to the gelatinous mass;

thermally conductive fibers extending into the mass; and

wherein the thermal transfer material meets the parameters of (1) having a total mass loss of less than 1% in a day under conditions of 125°C and a pressure of 10^{-6} torr; and (2) having a volatile condensable mass loss of less than 0.1% in a day under the conditions of 125°C and a pressure of 10^{-6} torr; wherein the volatile condensable mass is defined as mass which can be recondensed on a surface at a temperature of 25°C after the mass is lost from the thermal transfer material.

34. The material of claim 33 wherein the gelatinous mass comprises at least one of silicone and siloxane.

35. The material of claim 33 wherein the surface of the substrate consists essentially of TEFLON™.

36. The material of claim 33 wherein an entirety of the substrate consists essentially of TEFLON™.

37. The material of claim 33 wherein the surface of the substrate comprises TEFLON™.

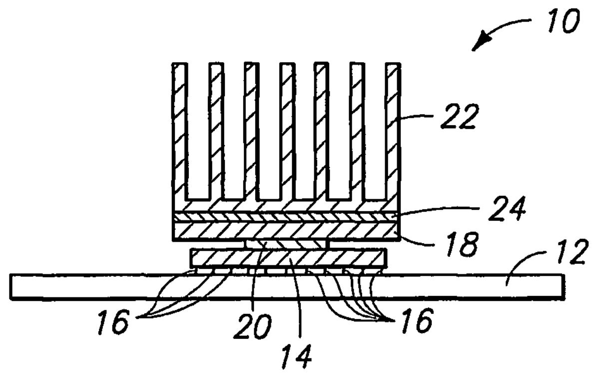


Fig 1

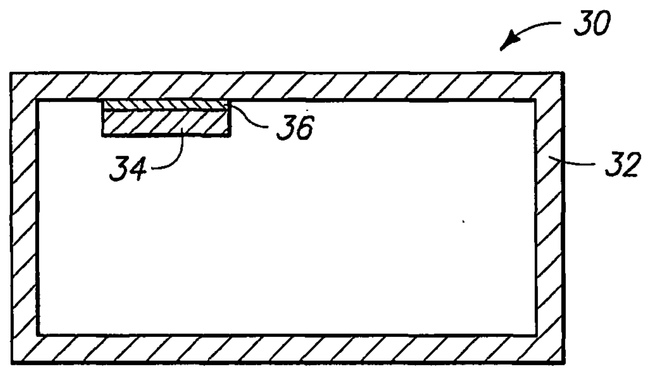


Fig 2
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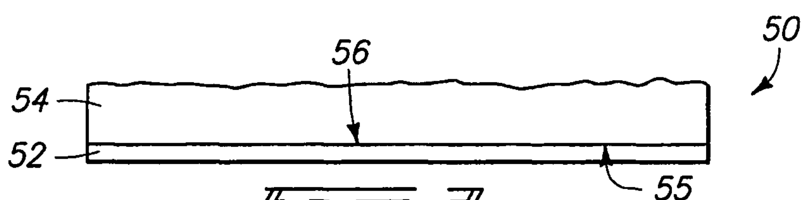
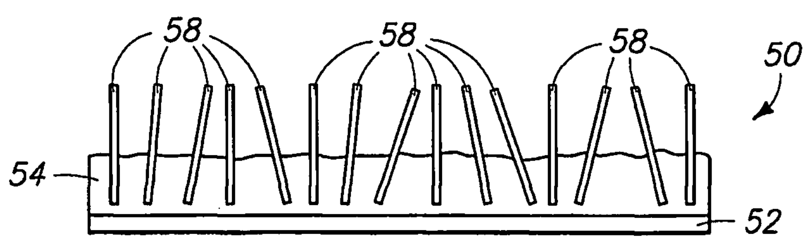


Fig 3



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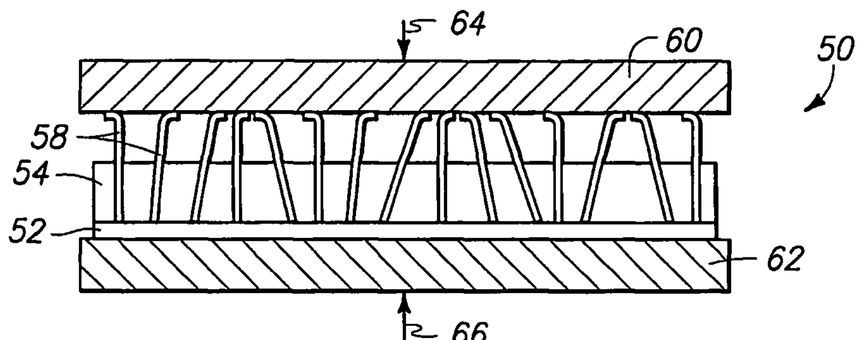

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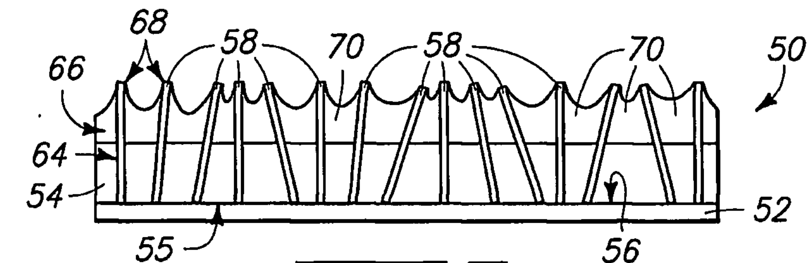

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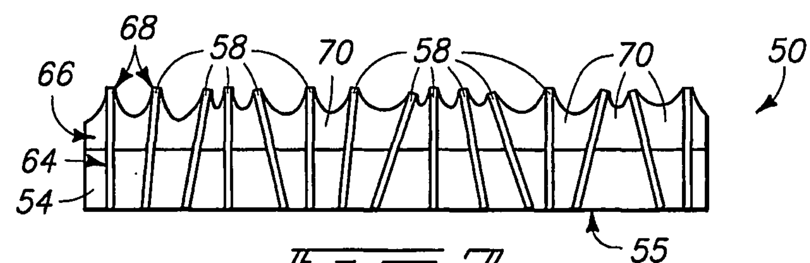


Fig 7

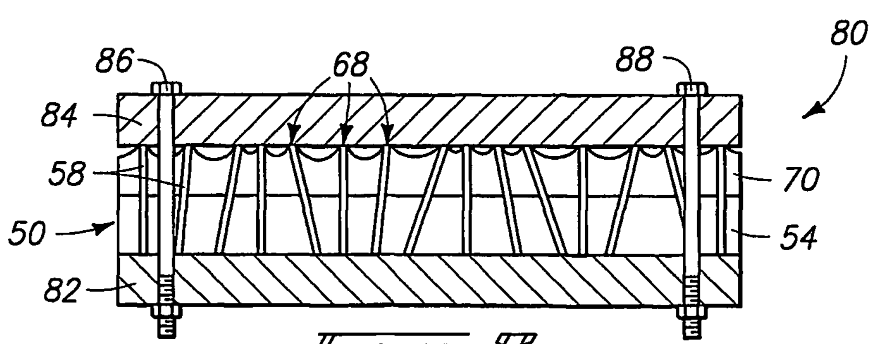


Fig 8

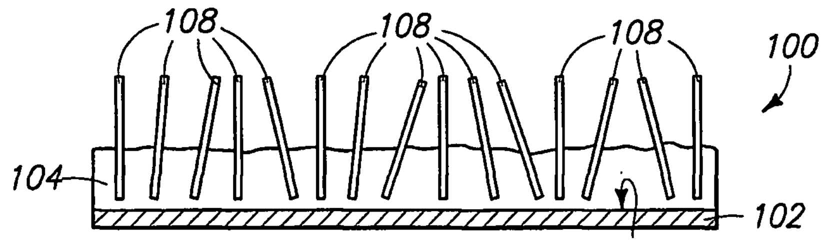


Fig 9

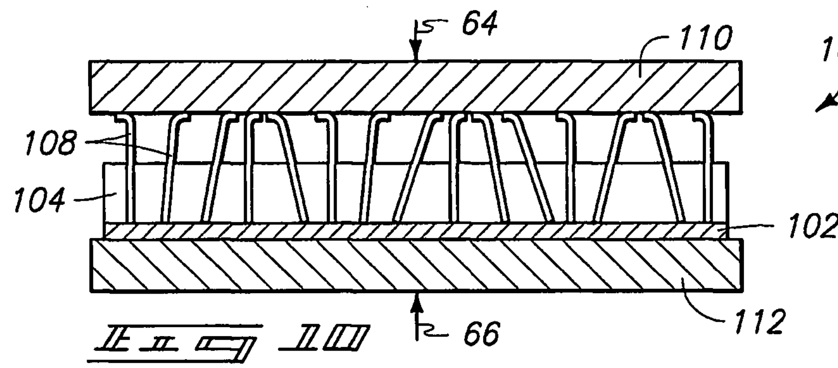
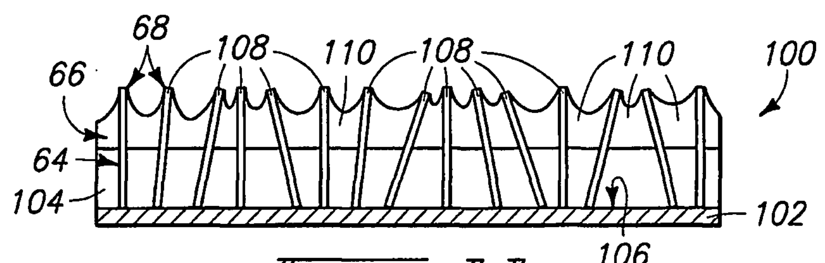


Fig 10



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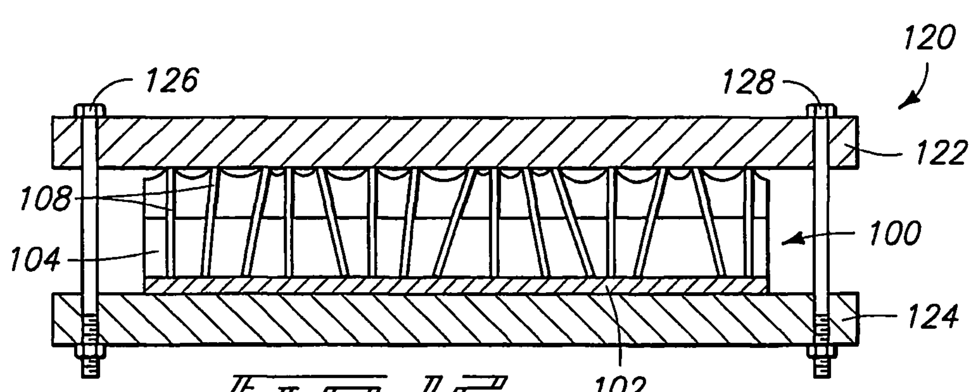

Fig 12

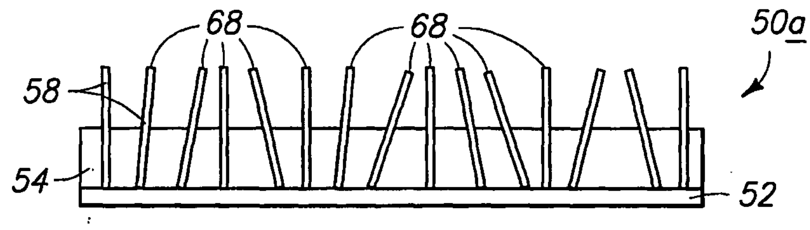

Fig 13

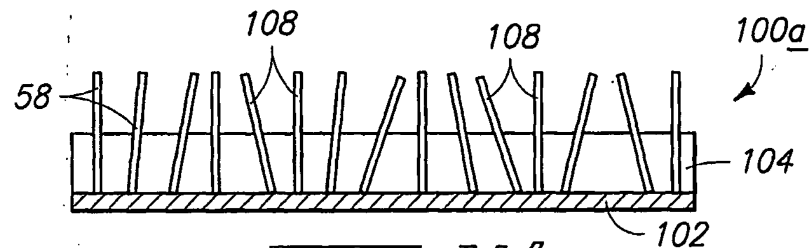

Fig 14

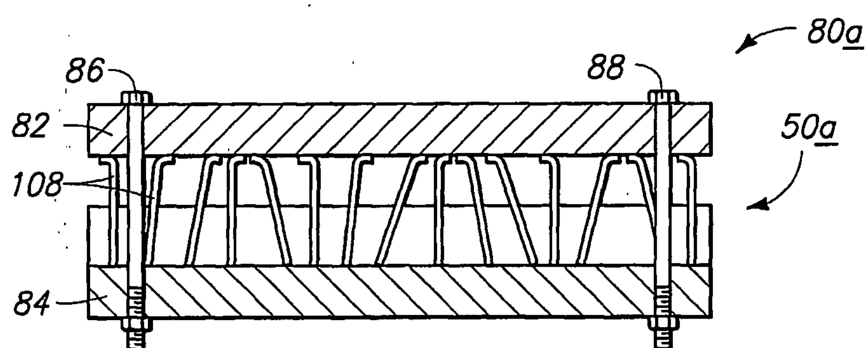

Fig 15

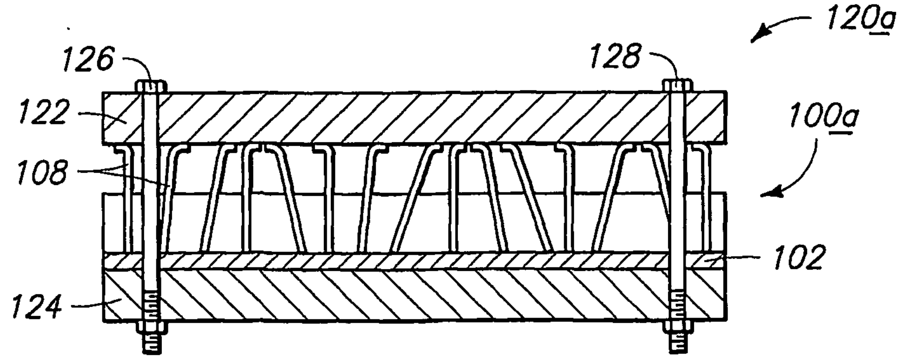

Fig 16